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SUNSEED – an evolutionary path to smart grid comms over converged telco and energy provider networks

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***Abstract*— SUNSEED, "Sustainable and robust networking for smart electricity distribution", is a 3-year project started in 2014 and partially funded under call FP7-ICT-2013-11. The project objective is to research, design and implement methods for exploitation of existing communication infrastructure of energy distribution service operators (DSO) and telecom operators (telco) for the future smart grid operations and services. To achieve this objective, SUNSEED proposes an evolutionary approach to converge existing DSO and telco networks, consisting of six steps: overlap, interconnect, interoperate, manage, plan and open. Each step involves identification of the related smart grid service requirements and implementation of the appropriate solutions. The promise of SUNSEED approach lies in potentially much lower investments and total cost of ownership of future smart energy grids within dense distributed energy generation and prosumer environments.**

I. Introduction

SUNSEED – "Sustainable and robust networking for smart electricity distribution" is a FP7 STREP project, partially funded under the call FP7-ICT-2013-11, objective ICT-2013.6.1 Smart Energy Grids [1]. The purpose of this specific call was to organize and concentrate the efforts of stakeholders from the energy and telecom sectors, in order to create common ICT infrastructure for future smart grid services. The target outcome is a cost-effective solution that incorporates the existing and future communication networks of both energy and telecom providers, enabling exchange of the data among end-users, power generating facilities and operators, and offering open service platform for implementation of the advanced grid monitoring and control functionalities. The expected impact of the call includes the following:

- Reduction of the percentage of energy lost during energy distribution.
- Reduction of the gap between energy produced and energy consumed.
- Increase of renewable energy sources and combined heat and power generation, which are connected to the distribution grid.
- Reduction and shifting of peak loads.

Related issues have been also recently considered by the European parliament [2], by setting the following binding targets by 2030: (i) 40 % cut in greenhouse gas relative to 1990, (ii) at least 30 % of energy generation from renewable sources and (iii) 40 % improvement in energy efficiency.

The key research challenges to reach the target outcomes, as outlined by the call and addressed in SUNSEED, are:

a) Sharing of the backbone infrastructure and the last mile connectivity, considering not only technologies, but also the appropriate business models to deliver significant cost and investment savings.

b) Improving robustness/reliability of the existing communication infrastructure in order to cope with mission-critical services that require milliseconds response times.

c) Research and design of ICT technologies for active electricity network management, demand/response, load balancing and forecasting, and congestion management.

d) Developing telecommunications services and platforms for energy distribution, while considering: access to customer information and consumption data, data ownership, usage and the associated level of security, system reliability, long-term availability, business models,and avoidance of vendor lock-in.

The organization of the rest of the paper is as follows. An overview of the smart grid communication infrastructure, as projected by the European Commission (EC), is presented in Section II. The SUNSEED project objectives and visions are presented in Section III. Section IV elaborates the associated workplan. The paper is concluded in Section V, with a brief description of a pilot site deployment that will be used to implement and validate the project findings.

II. EC Vision on Smart Grid Communications

Recently, EC issued several documents that broadly influence future developments of smart energy grids and, in particular, their accompanying communications infrastructure. A public consultation [3] ascertains that civil works can take up to 80 % of total investment, a 30 % portion being attributed to lack of reuse of existing communication infrastructure as well as cooperation between utilities. The smart grid market is enabling new types of services/industries foreseen in the Digital Agenda 2020. In order to attain it, the focus should be put on the existing infrastructure, more efficient deployment by all utilities and enabling equal access to third party operators.

The 2011 EC proposal for regulation [4] deals with the priorities related to broadband communication networks and digital service infrastructures. An important recommendation is to exploit the synergies between the deployment of broadband telco and other utilities networks, in particular those related to smart electricity distribution. The goal is to enable public broadband access with actors ranging from energy utilities, telcos, municipalities and multi-operator partnerships, and in this way to create an infrastructure for provisioning of smart energy services that meets the needs of future producers and consumers of energy. The foreseen smart energy services are divided into *core* and *generic* services. The core services include communications infrastructure, deployed in tandem by utilities and telcos, having an accompanying IT infrastructure within substations, enabling monitoring and control of power management, automation between energy service providers, telcos, energy utilities and consumers. On the other hand, the generic services will be provided by energy services companies, delivering functionality for customers to optimize the energy usage by managing the energy demand, renewable energy sources, storage capacities (e.g., e-car batteries), etc.

The EC communication [5] focuses on enabling diverse and innovative energy services to consumers, in particular by offering high quality of service, added value of ancillary services, or bundling different types of services, e.g., energy distribution with broadband communications. Furthermore, the classic roles of DSO are reconsidered by introducing aggregators[1], energy service providers and telcos to foster future development of the local distribution smart grids and energy services.

The EC memo [6] specifies that one of the goals of smart grid is to better plan the use of infrastructure and balance the system, achieving the following benefits: increased share of renewable energy and decentralized generation coexisting with the centralized one, providing consumers with the ability to adapt consumption to price and thus increase energy efficiency, optimize management of electricity grid and boost EU technology development.

The EC directive 2009/33/EC [7] aims to stimulate the market for clean, energy efficient, low or zero CO2 emissions road transport vehicles. Relatedly, in January 2013, EC issued a memo [8], noting that one of the three barriers to full scale adoption of clean fuel vehicles is the lack of a recharging infrastructure. Recharging stations are not only a technical prerequisite, but also a critical component for consumer acceptance and require instant communication capabilities for authentication and billing. The EC adopted requirements for a minimal infrastructure that should be implemented by 2020, thus meeting the market size targets of e-cars established by EU member states. By 2020 there should be 800 K e-car charging stations, i.e., on average, a charging station per 500-1000 inhabitants. Reaching the 2020 targets requires a 60 % annual growth rate of installed charging stations.

[1] Aggregators are companies that act as representatives who purchase, negotiate and/or sell electricity on behalf of a group of consumers and/or electricity generators.

III. Project Overview

SUNSEED is a 3-year project that started in February 2014. The project consortium consists of a DSO operator, a telecom operator, a measurement and certification lab, two industrial and three academic partners [9]: Telecom Slovenia (coordinator); Aalborg University, Denmark; Elektro Primorska, Slovenia; Elektroservisi, Slovenia; Jozef Stefan Institute, Slovenia; Gemalto SA, France; Gemalto M2M Gmbh, Germany; TNO, The Netherlands and Toshiba Research Labs, UK.

The project objectives can be succinctly listed as follows:

1. To develop guidelines, implement and demonstrate solutions for DSO-telecom converged network for distribution grids incorporating distributed energy generators (DEGs).
2. To develop advanced measurement and control sensor node for wide area measurement system (WAMS) application.
3. To develop and implement intelligent analytical and visual tools for real time smart grid management.

A more detailed partitioning of the objectives reveals the following research and development challenges:

- Development of business models & techno-economic analysis taking into account converged DSO & telecom communications infrastructures and "what-if" scenarios of communications network design, network ownership, operations and maintenance. Proposing a win-win model and stimulating participation of new energy market stakeholders on open smart grid infrastructures.
- Design and implementation guidelines for fixed-line and wireless communication infrastructure, including different topologies, operation-administration-management solutions at different network layers, as well as the required scalability, survivability and security.
- Development of a metering/control node, constituting the core of WAMS application, which is capable of fast measurement updates ($\leq$ 5 s) of key energy grid parameters for power quality monitoring (e.g. P, Q, V, harmonics, voltage dips) that enables real-time event tracking and control.
- Re-engineering of cellular communication solutions to support robust operation in distributed grids with high density.
- Development of secure end-to-end communication mechanisms.
- Software solutions to integrate the information from the energy and the communication networks, GIS, and open databases augmented with real time GIS visualization.
- Implementation of a large scale field trial (~1000 nodes), which includes diverse set of node types: DEGs, e-car charging stations, cellular base stations, homes. The target applications are real time management, control,

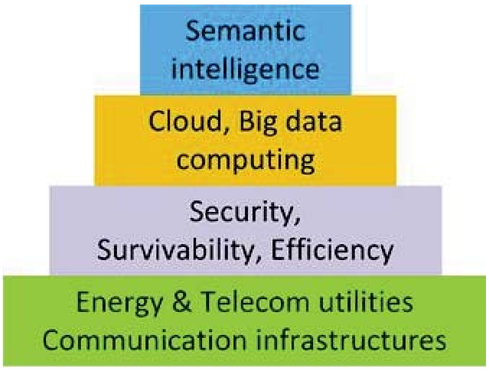

Figure 1 SUNSEED smart grid model.

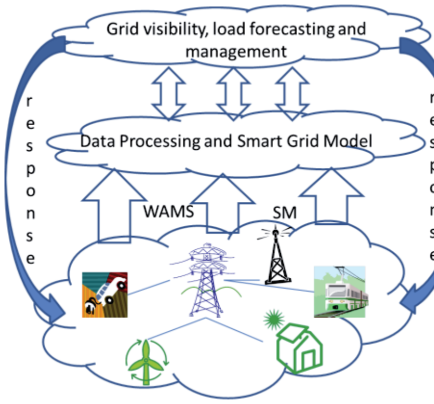

Figure 2 SUNSEED high-level smart grid representation.

and visualization of power and information flows through a converged infrastructure.

The SUNSEED smart grid model, inspired by the Maslow pyramid, is illustrated in Fig. 1. The underlying layer is comprised of both DSO and telco communication infrastructures that should be reused to the maximum possible extent. The major premise is that there is already enough communication bandwidth and capacity installed in the telco owned networks, which can be made available for the future smart grids. Also, all future upgrades and redesigns of the telco networks should be done by considering evolution of a dense smart grid. Finally, the developed solutions should work seamlessly and efficiently over both the DSO and the telco networks.

The information security in smart grid is of paramount importance due to its distributed nature that incorporates thousands of communication nodes and where each node is a potential intrusion target. An important observation in this regard is that smart grid security requires a specific design [11], [12]. Further, the architecture and the topology of the communication network must be highly resilient to failures; SUNSEED will seek to achieve this through a heterogeneous mix of solutions on physical and logical/protocol levels.

The decentralized smart grid poses a whole new set of management and control challenges compared to the centrally managed grids of today. Coping with more complex control models in real time (e.g., microgrid control or scheduling of e-car charging), requires a high reliance on decentralized computing infrastructure in form of on-demand scalable private cloud solutions. These will accommodate and process vast amounts of data presented in stream fashion.

The ultimate system goal is to become "intelligent", i.e., to be able to learn from the previous states and data inputs and predict the preventive measures in order to maintain safe and stable operation of the complete smart grid system. The SUNSEED approach for implementation of the required knowledge extraction and semantic intelligence algorithms will be based on a probabilistic approach, involving multiple classification methods running in parallel in order to assure improved accuracy. The net results of the semantic algorithms will solve a particular problem of a use case, e.g. energy grid state estimation based on the sensory measurement data from WAMS nodes and failure prediction and/or location.

IV. THE WORK PLAN

The smart grid system under investigation in SUNSEED is illustrated in Fig. 2. The data is collected from the physical electricity grid infrastructure through WAMS nodes and smart meters (SM). It is then processed and inserted in the smart grid models and, finally, represented to the smart grid management centers and utilized into the algorithms for electricity grid load forecasting and management.

In order to develop the necessary facilities for the smart grid system, the SUNSEED work plan consists of three phases: requirement/exploration phase (1st project year), solutions development phase (2nd project year) and trial phase (3rd project year). For the SUNSEED trial plans the reader is referred to Section V.

In the requirement and exploration phase SUNSEED will define several use cases that are both essential and typical for the functioning of the future smart grids. At the moment of writing, the following list of use cases is under consideration:

1. **Demand response on a massive scale** for a prosumer smart grid, with myriad of possible renewable energy sources (photovoltaics, wind, co-generation) and energy storage (battery, fuel cell, e-car battery). The key requirement are: support for high density of smart grid communication nodes (> 1000/cell sector), each with moderate bandwidth requirement (< 100 kbps).
2. **Voltage drop measurement on an energy grid segment**. This use case involves measuring of energy grid voltages at referent points in the grid and derivation of the accurate voltage grid graph in real time for automatic control and stability purposes. The key requirements are: high bandwidth smart grid communication nodes (> 1 Mbps) of low density (< 100/cell sector).
3. **Survivability during natural disasters and massive energy grid outages**. This use case focuses on the availability of smart grid, based on worst-case scenarios of massive natural disasters (e.g. floods, sleet) with multiple faults leading to cascading failures of critical infrastructures. The key requirements are: high availability of communication paths with dynamic rerouting over heterogeneous infrastructures (wireless, cellular, fiber, copper, PLC).

One of the main challenges related to these use cases is the foreseen density of smart grid measurement nodes per sector, which cannot be supported by 3G or 4G cellular access[2,3]. At present, the communication between the management center and the smart meters installed in homes is multilayered. The typical communication path comprises the following links: smart meter is first connected via power line communications to PLC concentrator, then via cellular network to the cellular network core node at the carrier, and finally, via fiber/VPN connections to the management/control center of the utility company. Clearly, this is an interim solution and the future dense smart grids will require direct node communication with the utility/DSO grid management center. One of the main activities foreseen in SUNSEED is reengineering and enhancing the current cellular standards, such that the capacity and reliability of the access network is substantially improved. Specifically, we aim to explore the applicability of solutions that modify the upper layer parameters of the access mechanism, exploiting the existing but unused degrees of freedom, as shown in [15][16]. In this way, the physical layer of the access network remains unchanged, minimizing the implementation complexity.

The use case of voltage status visibility stems, on one hand, from the large decentralization envisioned in the future smart grids (e.g., microgrids) and, on the other hand, the requirement for real time monitoring, control and systems state estimation. The key solution component is a metering and control node with a high speed (e.g., < 5 s acquisition metering time). It can complement the existing SCADA devices by measuring state and quality of several energy grid parameters with real-time, high-bandwidth, low-latency link to the management center. Failure prediction and state estimation requires further processing of large quantities of measured data. Finally, strict time synchronized measurements (time instant and phase) are required within the whole grid graph topology.

The survivability use case is largely motivated by the recent natural disaster in Slovenia where an excessive sleet caused massive infrastructure outages (e.g., 25 % of electricity grid, 25 % of base station towers, cascade HV grid towers structural failures). This requires focusing the design of the communications solutions in a way that assures either partial or localized energy grid operation under such conditions. This is in line with other research findings [17], where the future communication solutions in distributed smart grids must concentrate on latency, bandwidth and reliability.

The phase of exploration and requirement specification will be finalized by deriving the corresponding functional, business, and communication requirements.

In the *solution development phase*, three important research directions are defined:

1. Design of communications networking solutions that support the defined use cases, under the constraints that they build upon the existing communication infrastructure at the DSO and telco and that they are both technically and economically viable and thereby requiring minimal investment.
2. Design and prototyping a WAMS node suitable for facilitating the defined use cases, which has measurement and local processing capabilities, as well as multiple communication interfaces.
3. Design and implementation of a large data processing functionality that feeds the necessary input into a smart grid graph model algorithms for electricity load forecasting and management.

The solution development phase will be finalized by specifying the guidelines for communication networks to support the smart grid, including the selection of communication technologies and standards [18], communication architecture and description of the security solution description. We focus on the current 3GPP LTE Rel12, WiFi IEEE 802.11ac capabilities and explore possible L1/L2 on S1 link or MAC changes to facilitate M2M and smart grid communication [19], [20]. Further, a WAMS prototype will be delivered, which will be incorporated in the trial set-up and smart grid models, including electricity load visibility, forecasting and management.

V. PILOT SITE

One of the key features of the SUNSEED is a set-up of a large scale pilot site. The purpose of the pilot is to demonstrate and study in practice the concepts and the theoretical results developed within the project.

The pilot site will be installed within the Elektro Primorska distribution network, see Fig. 3. Elektro Primorska has 130 000 users, making the pilot relevant for medium-sized DSOs. The target of number measurement nodes is approximately 1000, comprising SMs (ca. 600 nodes), MV/LV substation meters (ca. 50 nodes) and WAMS nodes (ca. 400 nodes). The target reporting periods will range from 10 s to 1 min, with a possibility of dynamic adjustments via a feedback mechanism. Fig. 3 also depicts the coverage of Telecom Slovenia cellular network of the Elektro Primorska grid, based on a field data. The depicted radio coverage is calculated on a 3D, 10 m terrain map with a modified COST 231 radio propagation model [21]. Clearly, there is already a complete coverage of the distribution grid in urban and semi-rural areas, which is a good starting point for the SUNSEED pilot site deployment. The existing SCADA network of the DSO is not going to be affected by pilot, since the WAMS nodes and communication network will be established in parallel. This guarantees continuity of DSO operations and information security during the pilot operation. The data from the WAMS is transferred through a secured VPN between the telecom carrier and the DSO operators. It will be displayed at both places, thus also demonstrating concurrent operation of two management sites.

Finally, we note that the field trial will also build upon experiences gained from FP7 projects eBADGE [22] and Smart2Cnet [23], including reuse of some of eBADGE locations, infrastructure, sensor nodes and communications paths.

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[2] Note that 5G envisions specific M2M support for low bandwidth nodes [13].

[3] Note that according to the Electricity Directive (2009/72/EC) [14] at least 80% of consumers have to be equipped with smart meters by 2020, whereas 15 % is the norm today in EU member states.

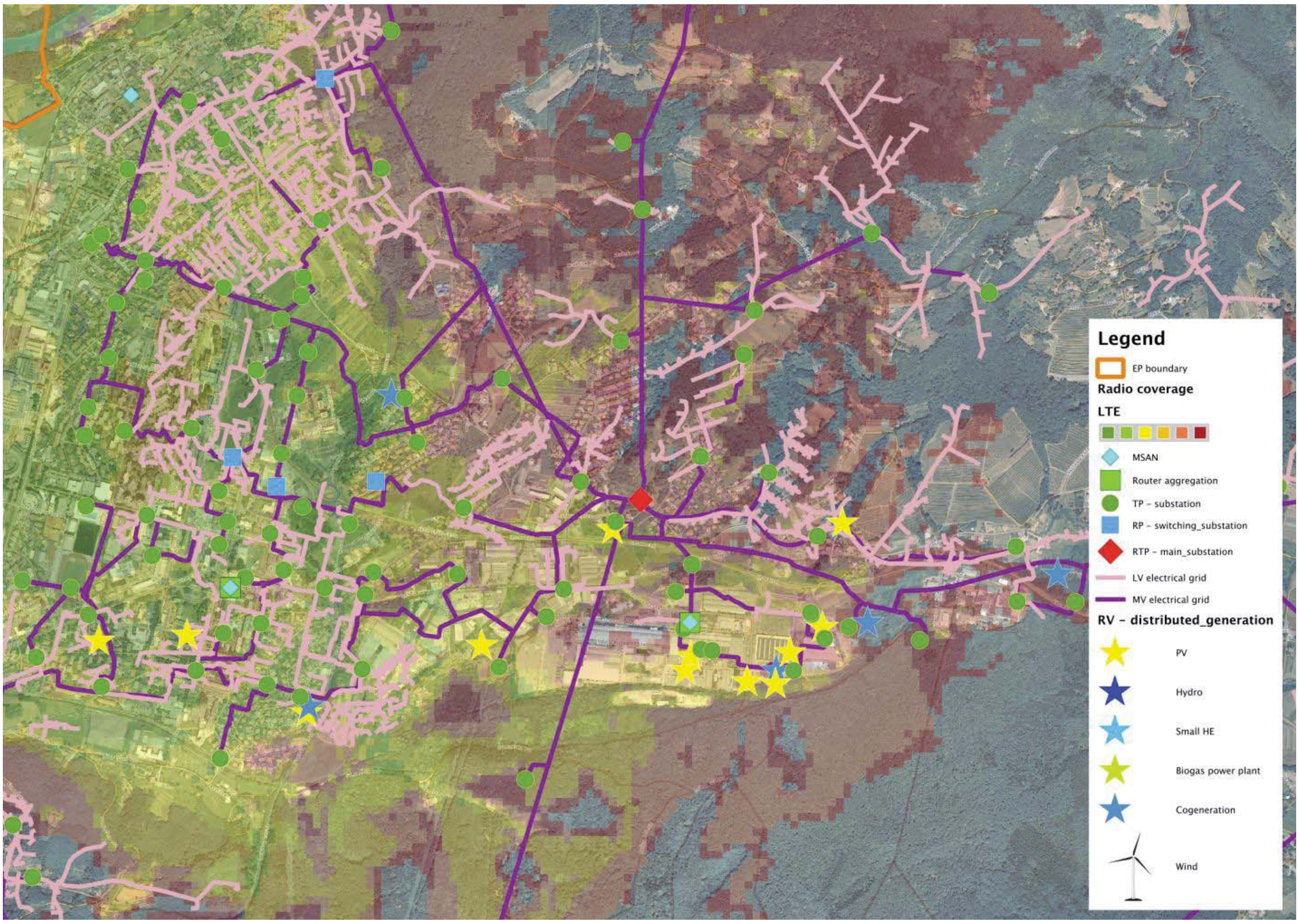

Figure 3 Elektro Primorska distribution grid and the corresponding Telecom Slovenia cellular network coverage.

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